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WOOD-DECAY FUNGI ASSOCIATED WITH SUBTERRANEAN TERMITES (RHINOTERMITIDAE) IN LOUISIANA

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Abstract.—Wood-rotting fungi associated with the subterranean termites *Coptotermes formosanus* and *Reticulitermes* spp. in southern Louisiana were examined. Fruiting bodies of thirty basidiomycetes and one ascomycete were collected from termite-infested logs. All of the basidiomycete species caused white rots. These fungi previously have been reported to repel termites. In several cases we found *Reticulitermes* feeding on basidiocarps, and species of both termite genera were attracted to *Ganoderma* basidiocarps in choice tests in the laboratory.

Although termites often augment their nitrogen-poor diets by feeding on decayed wood containing fungal mycelia (Sands, 1969), the interactions between termites and wood-rotting basidiomycetes are more complex. Some fungal species attract termites (Esenther et al., 1961), while others reportedly inhibit feeding (Amburgey, 1979). The observation that the foragers of *Reticulitermes flavipes* (Kollar) make trails to branches decayed by the basidiomycete *Gloeophyllum trabeum* (Pers.: Fr.) Murr. (Esenther et al., 1961) led to the discovery that extracts of this fungus are attractive to a number of subterranean termite species (Allen et al., 1964). One of the attractive chemicals is apparently identical to the trail pheromone of *R. virginicus* (Banks) (Howard et al., 1976). Laboratory studies have since demonstrated that termite response to *G. trabeum* and other decay species is dependent on the fungal strain, the fungal substrate, and the bioassay technique used (Becker and Lenz, 1976; Esenther and Beal, 1979).

The dynamics of termite-fungal associations in nature are poorly known, and it has been suggested that these associations depend upon rot type. White rot basidiomycetes catabolize both cellulose and lignin, as do termites (Waller and La Fage, 1987), while brown rots leave a lignin residue (Gilbertson, 1981). Preliminary field observations suggest that termites avoid wood decayed by white rot fungi (Amburgey and Beal, 1977), but several white rot species have been shown to be phagostimulatory in laboratory bioassays (Gilbertson, 1984). The importance of brown and white rot fungi in termite feeding is therefore uncertain, as few natural termite-fungal associations have been identified.

In the present study we examined the wood-rotting fungi associated in southern Louisiana with the subterranean termites *Coptotermes formosanus* Shiraki and *Reticulitermes* spp. *Coptotermes formosanus* is a pest species introduced into the area approximately forty years ago (La Fage, 1986), and species of *Reticulitermes* are native. We were interested in comparing fungal associations with these species in natural habitats.

Previous studies of termite-fungal interactions have focused on termite response to fungal mycelia. During our study we found termites feeding on fruiting bodies of several species. Therefore we also tested termite attraction to fruiting bodies of several fungal species to determine whether some were more attractive than others.

METHODS

Termite species.—The Formosan subterranean termite *Coptotermes formosanus* has large colonies numbering several million individuals (Su et al., 1983) that build nests underground or in tree hearts. This species attacks dead wood and live trees (Lai et al., 1983) and feeds on both sound and decayed wood (Smythe and Carter, 1970; Amburgey, 1979). *Coptotermes* is readily identifiable by its numerous distinct soldiers, which have oval heads with a large anteriorly directed fontanelle (Weesner, 1969).

Reticulitermes colonies contain several hundred-thousand individuals (Howard et al., 1982) that live underground and forage on sound and decayed dead wood (Smythe and Carter, 1970; Amburgey, 1979), including dead branches on live trees. Soldiers of the most common *Reticulitermes* species in Louisiana, *R. flavipes* and *R. virginicus*, are difficult to distinguish; species identifications can be made reliably only by using alates. Thus associations were recorded as *Reticulitermes* sp. for this genus. Because the workers of *Coptotermes* and *Reticulitermes* are extremely similar morphologically, we recorded only "termite workers" if no soldiers could be found. However, *C. formosanus* soldiers are very numerous and aggressive, while *Reticulitermes* soldiers are rare (Howard and Haverty, 1981); workers without soldiers were therefore probably *Reticulitermes*.

The dry-wood termite, *Kalotermes approximatus* Snyder (Kalotermitidae), was found in one collection. This termite has small colonies of several thousand individuals, and nests are constructed entirely within dead wood (Weesner, 1965).

Field associations with decay fungi.—We collected fungal basidiocarps from termite-infested logs and live trees in Baton Rouge, Lake Charles, and New Orleans, Louisiana. Identifications were made by MB and RLG; in some cases, basidiocarps were deteriorated, and identifications could be made only to genus. Fungal presence was determined by basidiocarp presence. Because decay isolations were not made, additional species may have been undetected. It is not known if fungal mycelia of detected species were viable. Host woods were identified when possible.

Bioassays with fungal fruiting bodies.—We tested the response of *Coptotermes formosanus* and *Reticulitermes* sp. to basidiocarps of *Ganoderma lucidum* (W. Curt.: Fr.) Karst. (Ganodermataceae), *Phellinus gilvus* (Schw.) Pat. (Hymenochaetaceae), *Hexagonia hydnoides* (Fr.: Sw.) M. Fidalg. (Polyporaceae) and *Pycnoporus sanguineus* (L.: Fr.) Murr. (Polyporaceae) by using a modification of the technique of Allen et al. (1964). Although laboratory bioassays do not necessarily reveal field preferences, they are important in providing preliminary data for more comprehensive studies. Basidiocarps were collected from logs without termites, and were dried at 60°C for at least 48 h prior to the bioassay. We tested six colonies of both *Coptotermes* and *Reticulitermes* and used two replications per colony (only one replication for one of the *Reticulitermes* colonies) for each test. One hundred termites per test were placed in a 100 × 15 mm petri dish filled with 2% Difco Bactoagar to maintain a high-humidity environment. One 0.1 g piece of each basidiocarp was arranged equidistant from the other species in the petri dish. The number of termites in a dish that were on each basidiocarp was recorded at five minutes, 24 hours, and six days after set-up. Data were analyzed for each time interval with analysis of variance (SAS GLM procedure, SAS Institute, Cary, North Carolina).

RESULTS

Termite-fungal associations.—We collected fruiting bodies of one ascomycete genus and thirty species of basidiomycetes comprising nine families and two orders (Table 1). All of the basidiomycetes collected cause white rots. In several cases, different fungal species were found in the same log, so that not all decays were directly associated with termites. *Coptotermes* and *Reticulitermes* were never found together.

In several cases, *Coptotermes* and *Reticulitermes* attacked wood decayed by the same species of fungi. *Hyphoderma* sp., *Phellinus gilvus, Schizopora paradoxa, Ganoderma lucidum,* and *Stereum ostrea* were associated with both *Coptotermes* and *Reticulitermes,* and *Kalotermes* was found with *Reticulitermes* in a log decayed by *Phellinus gilvus.* We observed *Reticulitermes* feeding on basidiocarps of *Hexagonia hydnoides, Inonotus cuticularis,* and *Ganoderma lucidum,* indicating that fruiting bodies as well as decayed wood were phagostimulatory.

Bioassays with fungal fruiting bodies.—The results for *C. formosanus* response to the fruiting bodies are shown in Table 2. At the five-minute check, significantly more termites were on the *Phellinus gilvus* basidiocarp ($P < .001$). After 24 h, there was a significant difference in the number of termites on the different basidiocarps ($P < .05$), with slightly more termites on *P. gilvus* and *Ganoderma lucidum* than the others. At six days, there were also significant differences in attraction of the different species ($P < .02$), again with slightly more termites on basidiocarps of *P. gilvus* and *G. lucidum.* There were significant differences among colonies after 5 min ($P < .001$) and 24 h ($P < .05$), but not after six days ($P > .05$).

Table 3 lists the results for *Reticulitermes* response to the basidiocarps. At five minutes, there were no significant differences among termites on the different basidiocarps ($P > .05$). Significantly more termites were on the *G. lucidum* basidiocarp after 24 h ($P < .001$) and also after six days ($P < .001$). There were significant differences in response among colonies at the six-day check ($P < .001$).

DISCUSSION

Most fungal species associated with termites in our study were white rot basidiomycetes, demonstrating that *Coptotermes* and *Reticulitermes* do not avoid these species in nature. Whether white rots actually attracted termites or were incidental to termite attack on the host wood remains to be determined.

We observed no brown rot fungi in this study, possibly because brown rot fungi prefer softwood hosts (Gilbertson, 1981), and we sampled primarily hardwoods. In addition, white rot fungi outnumber brown rot fungi (Gilbertson, 1980), so that we were less likely to encounter brown-rotted wood. Field observations of subterranean termites associated with brown rots have been limited to a few accounts (Esenther et al., 1961; Williams, 1965).

Kovoor (1964) reported that wood decayed by the white rot fungus *Ganoderma applanatum* (Pers.) Pat. is toxic to *Microcerotermes* (Termitidae). In our study, we did not encounter *G. applanatum,* but both *Coptotermes* and *Reticulitermes* were collected from wood decayed by *G. lucidum,* and basidiocarps of this species were attractive to both genera in laboratory tests. It is clear that detailed information on termite-fungal associations in nature must be gathered before we can make generalizations about the effects of different decay species on termite feeding.

Although subterranean termites can survive on sound wood of some species (Smythe and Carter, 1970; Mannesmann, 1973), mycophagy may be important to natural host selection. Almost all of the subterranean

Table 1. Fungi associated with termites in southern Louisiana. W = white rot, L = live tree, D = dead wood, R = *Reticulitermes* spp., C = *Coptotermes fomosanus,* K = *Kalotermes approximatus,* t = termite workers not associated with soldiers. Number of fungus-termite associations found is indicated in parentheses. Collection sites were near Baton Rouge (BR), Lake Charles (LC), Livingston Parish (LV) or New Orleans (NO).

Fungal Species	Rot	Host Wood (L/D)	Site	Termite
Basidiomycetes				
Tremellales				
Auriculariaceae				
Auricularia polytricha (Mont.) Sacc.	W	*Celtis laevigata* Willd. (L)	NO	C (3)
	W	*Quercus shumardii* Buckly (D)	NO	C (1)
Tremellaceae				
Clitocybe tabescens (Scop:Fr.) Bres.	W	pine (D)	LC	R (1)
	W	tree trunk (D) (only mycelium)	LC	C (1)
Aphyllophorales				
Auriscalpiaceae				
Gloeodontia discolor (Berk. et Curt.) Boid.	W	tree trunk (D)	BR	t (1)
Corticiaceae				
Bjerkandera adusta (Willd.:Fr.) Karst.	W	hardwood (D)	BR	t (1)
Botryobasidium sp.	W	pine (D)	LV	R (1)
Confertobasidium olivaceoalbum (Bourd. and Galz.) Jul.	W	wood (D)	BR	R (1)
Hyphoderma setigerum (Fr.) Donk	W	wood (D)	BR	R (1)
Hyphoderma sp.	W	wood (D)	LC	C (1)
	W	pine (D)	LV	R (1)
Phlebia rufa Pers.:Fr.	W	wood (D)	BR	t (1)
Schizopora paradoxa (Fr.) Donk	W	wood (D)	LC	C (1)
	W	wood (D)	NO	R (1)
	W	wood	BR	t (2)
	W	hardwood (D)	LC	R (1)
	W	wood	NO	t (2)
	W	hardwood (D)	BR	t (1)
	W	wood (D)	BR	R (1)
	W	*Liquidambar styraciflua* L. (D)	BR	R (1)
Scopuloides hydnoides (Cke. and Massee in Cke.) Hjortst and Ryv.	W	wood (D)	BR	R (1)
Steccherinum sp.	W	wood	BR	t (1)
Trechispora farinaceae (Pers.:Fr.) Liberta	W	wood	NO	R (1)
Ganodermataceae				
Ganoderma lucidum (W. Curt.:Fr.) Karst.	W	*Quercus virginiana* L. (L)	NO	C (1)
	W	*Q. virginiana* L. (D)	LC	R (1)
	W	wood (D)	NO	R (1)
	W	*Acer rubrum* L. (L)	NO	C (1)
	W	*A. rubrum* (L)	NO	t (1)

Table 1. Continued.

Fungal Species	Rot	Host Wood (L/D)	Site	Termite
Hymenochaetaceae				
Inonotus cuticularis (Bull.:Fr.) Karst.	W	*Quercus niger* L. (L)	BR	R (1)
Phellinus gilvus (Schw.) Pat.	W	hardwood (D)	NO	K (1)
	W	hardwood (D)	LC	R (1)
	W	hardwood (D)	LV	R (1)
	W	hardwood (D)	NO	R (1)
	W	*Quercus falcata* var. *pogodifolia* (L)	LC	t (1)
	W	wood	BR	t (1)
Phellinus robustus (Karst.) Bourd. et Galz.	W	*Fraxinus berlanderiana* A.DC. (L)	NO	C (1)
Phellinus sp.	W	hardwood (D)	BR	R (1)
Lachnocladiaceae				
Asterostroma sp.	W	*Salix* sp. (D)	NO	R (1)
Asterostroma-like	W	*Acer rubrum* L. (L)	NO	C (1)
Polyporaceae				
Coriolus versicolor (L.:Fr.) Murr.	W	tree trunk (D)	NO	R (2)
Fomes fomentarius (L. ex Fries) Kickx	W	hardwood (D)	NO	C (1)
Hexagonia hydnoides (Fr.:Sw.) M. Fidalg.	W	*Quercus shumardii* (Buckly)	NO	C(1)
Nigroporus vinosus (Berk.) Murr.	W	pine (D)	LC	R (1)
Perenniporia sp. Murr	W	hardwood (D)	LC	t (1)
	W	wood (D)	BR	t (1)
Pycnoporus sanguineus (L.:Fr.) Murr	W	hardwood (D)	LC	t (1)
Trametes versicolor (L.:Fr.) Pilat	W	wood (D)	LC	C (1)
Trichaptum sector (Ehrenb.:Fr.)	W	wood (D)	BR	R (1)
Stereaceae				
Stereum hirsutum (Willd.) Fr.	W	hardwood (D)	BR	R (1)
	W	wood (D)	LC	C (1)
Stereum ostrea (Blume et Nees:Fr.) Fr.	W	hardwood (D)	LC	C (2)
	W	wood (D)	NO	R (3)
	W	*Quercus shumardii* (Buckly) (D)	BR	C (1)
Ascomycetes				
Hypoxylon sp.		hardwood (D)	LC	R (1)
		hardwood (D)	BR	R (1)
		hardwood (D)	BR	t (1)
		wood (D)	NO	t (1)

Table 2. Mean (± SD) of numbers of *Coptotermes formosanus* workers on fungal basidiocarps after five min, 24 h and six d. Basidiocarps were presented in a four-way choice test to 100 termite workers. Two replications of six colonies were tested.

Time Interval	*Phellinus gilvus*	*Ganoderma lucidum*	*Pycnoporus sanguineus*	*Hexagonia hydnoides*
5 min	3.0 ± 3.5^{a}[1]	0.6 ± 1.0^{b}	0.0 ± 0.0^{b}	0.3 ± 0.5^{b}
24 h	1.7 ± 2.2^{a}	1.9 ± 3.0^{a}	0.7 ± 0.4^{a}	1.0 ± 1.6^{a}
6 d	2.1 ± 1.9^{a}	2.4 ± 2.1^{a}	0.2 ± 0.5^{a}	0.2 ± 0.5^{a}

	P Value		
	5 min	24 h	6 d
Colony	.0009	.0472	.0974
Basidiocarp	.0008	.0486	.0149
Colony × basidiocarp	.0013	.0102	.4817

[1] Means followed by the same letter in rows are not significantly different at $P < .05$, Tukey's studentized range test.

termites we have found in Louisiana were in rotted wood. Becker and Lenz (1976) found that several soft rot and brown rot fungi are attractive to *Heterotermes indicola* (Wasmann), *Reticulitermes flavipes* (Kollar), *Coptotermes amanii* (Sjostedt), and *Nasutitermes nigriceps* (Haldemann), and Hendee (1935) determined that the dampwood termite, *Zootermopsis angusticollis* (Hagen), survives better on decayed than on sound wood. Decayed wood may be favorable for several reasons, including enhanced nutrient content (La Fage and Nutting, 1978), decreased density (Wilcox, 1978), and detoxified wood allelochemicals (Williams, 1965; Martin, 1979).

Some decays can be critical to a termite's ability to use a host wood. Williams (1965) found that *Coptotermes niger* Snyder cannot feed on one of its primary hosts, *Pinus caribaea* Morelet, in Belize unless the heartwood is first decayed by the brown rot fungus *Lentinus pallidus* Berk. et Curt. Similarly, *C. formosanus* cannot eat sound heartwood of baldcypress, *Taxodium distichum* (L.) Rich (Carter et al., 1981), although this species is an important *Coptotermes* host in Louisiana. However, *Coptotermes* survived well on baldcypress heartwood decayed by the white rot fungus *Rigidoporus* sp. and an unidentified deuteromycete, (Waller and La Fage, unpublished

Table 3. Mean (± SD) of numbers of *Reticulitermes* sp. workers on fungal basidiocarps after five min, 24 h and six d. Basidiocarps were presented in a four-way choice test to 100 termite workers. Two replications of five colonies, and one of a sixth colony, were tested.

Time Interval	*Phellinus gilvus*	*Ganoderma lucidum*	*Pycnoporus sanguineus*	*Hexagonia hydnoides*
5 min	0.4 ± 0.5^{a}[1]	0.1 ± 0.3^{a}	0.0 ± 0.0^{a}	0.1 ± 0.3^{a}
24 h	1.8 ± 1.6^{b}	8.4 ± 6.6^{a}	0.3 ± 0.5^{b}	0.4 ± 0.5^{b}
6 d	0.1 ± 0.3^{b}	12.3 ± 9.0^{a}	0.1 ± 0.3^{b}	0.6 ± 1.2^{b}

	P Value		
	5 min	24 h	6 d
Colony	.5057	.0624	.0003
Basidiocarp	.1219	.0001	.0001
Colony × basidiocarp	.7597	.0246	.0001

[1] Means followed by the same letter in rows are not significantly different at $P < .05$, Tukey's studentized range test.

observations). Similarly, Perry et al. (1985) found that termite attack on heartwood of *Eucalyptus* and *Pinus* in Australia is secondary to fungal infection, which in turn is always associated with fire damage. Dependence on fungal decay for wood use therefore may be widespread in termites.

Further work may reveal the full extent of the importance of fungal decay in termite biology. Collins (1980) suggested that rhinotermitids are limited to mesic regions of Malaysia because they require decay fungi in their diets. More information on termite distributions and natural food preferences will help us understand the roles of these important detritivores in nature.

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